THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

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ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ON-BOARD EMISSIONS MONITOR**
APPLICATION:	**MEASURING VEHICLE EXHAUST EMISSIONS**
TECHNOLOGY NAME:	**REMOTE (Real-world Emissions Monitoring On-board Testing Equipment) On-board Emissions Monitor**
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The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, with stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Advanced Monitoring Systems (AMS) Center, one of seven technology areas under ETV, is operated by Battelle in cooperation with EPA's National Exposure Research Laboratory. The AMS Center has recently evaluated the performance of an on-board emissions monitor used to measure vehicle exhaust emissions. This verification statement provides a summary of the test results for the Real-world Emissions Monitoring On-board Testing Equipment (REMOTE) on-board emissions monitor (OEM).

VERIFICATION TEST DESCRIPTION

The verification was based on evaluating the performance of the REMOTE OEM under realistic operating conditions. Duplicate REMOTE OEMs were operated side-by-side throughout all portions of the verification test, which was conducted between May 7 and May 10, 2001, to estimate measurement precision. (A delay by the OEM vendor postponed preparation of this report until early 2003.) Overall accuracy (bias and precision) of the REMOTE OEM relative to emission measurements made by standard emission test equipment with a chassis dynamometer was assessed in three test vehicles: Chevrolet Cavalier (1998, 2.2 L, 4 cylinder, 22,697 miles); Chevrolet Tahoe (1997, 5.7 L, 8 cylinder, 63,857 miles); and Ford Taurus (1998, 3.0 L, 6 cylinder, 33,981 miles). Reliability and ease of use also were assessed. Two REMOTE OEMs (OEM A and B) were operated on two test cycles: the Federal Test Procedure (FTP) and the US06 cycle. In phase one of testing, three dynamometer test cycles were conducted with each of the three vehicles, to test whether interactions between vehicle type and test cycle have an impact on observed bias and precision. Four additional US06 cycles were performed on the Cavalier. Three of these were conducted at 30, 75, and 100°F, respectively, to assess the effect of temperature on OEM performance. The fourth US06 cycle was performed at 100°F with the Cavalier's air conditioner operating at maximum capacity to assess whether using vehicle accessories influences the performance of the REMOTE OEM. For all of the dynamometer test cycles, vehicle emissions were measured using flame ionization detection (FID) for hydrocarbons (HC), non-dispersive infrared spectroscopy for carbon monoxide (CO) and carbon dioxide (CO_2), and chemiluminescence for nitrogen oxides (NO_x). In phase two of testing, the duplicate REMOTE OEMs were installed in each test vehicle, and each vehicle was driven for approximately 15 minutes over each of two routes: one that was predominantly stop-and-go traffic and one that was predominantly sustained high-speed traffic. Second-by-second on-road data for HC, CO, NO_x, and CO_2 were collected by the duplicate REMOTE OEMs and used to visually compare the response of the REMOTE OEMs.

QA oversight of verification testing was provided by Battelle. Battelle QA staff conducted a technical systems audit, a performance evaluation audit, and a data quality audit of 10% of the test data.

TECHNOLOGY DESCRIPTION

The following description of the REMOTE OEM was provided by the vendor and does not represent verified information.

The REMOTE OEM is capable of measuring exhaust emissions from electronically controlled light-duty passenger vehicles and light trucks of model year 1996 and newer with on-board diagnostics (OBD) ports. The REMOTE OEM, using infrared techniques to measure CO, CO_2, and HC and electrochemical techniques to measure NO_x, is designed to provide real-time on-road emissions measurements and to derive test- and bag-averaged emissions during standard vehicle test cycles, as used in vehicle dynamometer testing. The REMOTE OEM provides second-by-second total HC, CO, CO_2, NO_x, and O_2 readings and total mass emissions summaries for individual test cycles. It includes a touch-screen computer and comes standard in a powder-coated aluminum housing.

The REMOTE OEM is installed in the passenger seat of the vehicle and connects to the vehicle in three locations. The cigarette lighter provides the power in the majority of installations (auxiliary battery optional), the OBD port under the dashboard provides the engine data stream, and the sample exhaust probe is inserted into the tailpipe.

VERIFICATION OF PERFORMANCE

Bias: Table 1 shows the results from the bias calculations. Considering all test data combined, the REMOTE OEM exhibited biases ranging between 34.8 and -11.2%. Considering all test data organized by test vehicle and test cycle, the REMOTE OEM exhibited biases for NO_x and CO ranging between -0.14 and 21.3% for OEM A and between -1.56 and 16.5% for OEM B. Biases for HC and CO_2 ranged between 8.09 and 63.9% for OEM A and between 9.53 and 44.7 % for OEM B.

Table 1. Percent Bias Values and Confidence Intervals for REMOTE OEM

Bias Pooling	OEM A				OEM B			
	HC	CO	NO_x	CO_2	HC	CO	NO_x	CO_2
Total Test								
% Bias	34.8	-7.95	-11.2	16.5	21.5	-2.07	1.96	22.2
±	9.56	1.80	3.35	2.50	4.82	2.84	3.90	3.60
Cavalier								
% Bias	**63.9**	**-0.14**	**-1.93**	**29.5**	**24.9**	**5.40**	**16.5**	**44.7**
±	**15.8**	**1.19**	**5.33**	**3.39**	**3.56**	**2.98**	**6.01**	**4.11**
Tahoe								
% Bias	**11.2**	**-12.9**	**-10.3**	**8.09**	**20.1**	**-7.79**	**-3.04**	**9.53**
±	**2.22**	**2.09**	**1.46**	**0.73**	**4.97**	**3.12**	**1.64**	**0.70**
Taurus								
% Bias	**29.4**	**-10.8**	**-21.3**	**11.8**	**19.4**	**-3.80**	**-7.58**	**12.3**
±	**2.42**	**1.05**	**1.42**	**0.39**	**6.12**	**1.94**	**1.32**	**0.34**
FTP cycles								
% Bias	53.9	-7.47	-18.1	19.2	20.6	-1.56	-4.57	25.2
±	12.8	1.40	2.05	3.29	3.48	2.63	1.98	3.78
US06 cycles								
% Bias	15.8	-8.42	-4.23	13.7	22.4	-2.57	8.48	19.2
±	2.62	2.22	4.07	1.39	6.11	3.19	5.06	3.57

Note: Bold rows show results by vehicle.

Unit-to-Unit Precision: Table 2 shows the results from the precision calculations. In nearly all cases, coefficients of variation (CVs) of the duplicate OEMs for all the emissions measured from all vehicles were less than 5%. The largest CV was reported for HC during the Cavalier test at 8.97 ± 11.6% over a tested range of 0.05 to 0.47 grams per mile (g/mi). The smallest CV was seen for CO during the Cavalier test at 1.11 ± 1.43% over a tested range of 0.70 to 12.0 (g/mi).

Reliability and Ease of Use: All data were collected as expected, and the REMOTE OEMs had no downtime during the tests. The REMOTE OEMs were installed in the vehicles with no difficulty for the on-road testing. Operation over a temperature range of 30 to 100°F had no adverse effect on OEM reliability, and operation over this range showed no consistent effect of temperature on OEM bias for any of the measured species.

Other Unit-to-Reference Method Comparisons: The second-by-second data for the reference method and the REMOTE OEM illustrate close agreement. A time delay between the reference monitors and the REMOTE OEM was due to the different lag times in sampling by the reference monitors.

The linear regression of OEM and FTP bag results shows that, except for the OEM A HC results (r^2 of 0.54), both OEM A and OEM B had coefficients of determination greater than 0.86 for all four emitted species. The slopes of the linear regressions for OEM A and OEM B relative to the FTP bag results were between 0.97 and 1.03 for CO_2 over a tested range of 300 to 620 (g/mi). The slopes were between 0.95 and 1.05 for CO over a tested range

Table 2. Unit-to-Unit Precision Results and Confidence Intervals for REMOTE OEM

Precision Pooling	HC	CO	NO_x	CO_2
Total Test				
% CV	6.04	2.54	4.03	3.17
±	2.66	1.12	1.78	1.40
Cavalier				
% CV	**8.97**	**1.11**	**4.73**	**4.89**
±	**11.6**	**1.43**	**6.10**	**6.30**
Taurus				
% CV	**4.77**	**2.32**	**4.59**	**1.99**
±	**6.15**	**2.99**	**5.92**	**2.57**
Tahoe				
% CV	**2.50**	**3.57**	**2.29**	**1.50**
±	**3.23**	**4.60**	**2.96**	**1.93**
FTP Cycles				
% CV	7.90	2.05	4.4	3.71
±	6.44	1.67	3.58	3.02
US06 Cycles				
% CV	4.77	2.32	4.59	1.99
±	2.65	2.40	2.95	2.05

of 0 to 13 (g/mi) and between 0.92 and 1.03 for NO_x over a tested range of 0 to 1.4 (g/mi). However, the slopes of the linear regressions for OEM A and OEM B were between 0.62 and 0.79 for HC over a tested range of 0 to 1 (g/mi). The HC results may be because of the different analytical techniques used (i.e., infrared absorption in the OEM measurements, FID in the reference measurements).

signed by Gabor J. Kovacs 7/16/03
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